A PRACTICAL TEST OF PRIMARY CELLS

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ARMOUR INSTITUTE OF TECHNOLOGY

1909

A PRACTICAL TEST OF PRIMARY CELLS.

A THESIS

PRESENTED BY

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TO THE

PRESIDENT AND FACULTY

OF

ARMOUR INSTITUTE OF TECHNOLOGY

FOR THE DEGREE OF

BACHELOR OF SCIENCE IN ELECTRICAL ENGINEERING

HAVING COMPLETED THE PRESCRIBED COURSE OF STUDY IN

ELECTRICAL ENGINEERING

1909

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Preface.

The following paper will be divided into six parts as follows:-

Part I.

The Intermittent Test.

Part II.

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Part III.

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Introduction.

From a commercial standpoint very little
has been done to show how primary batteries, especially
those of the dry type, stand up when subjected to
various tests. Considerable attention has been dir-
ected toward the actions of primary cells using various
liquids as electrolytes, and under various conditions.
Experimenters have directed their attention to this
class of primary batteries rather than to the so-
called 'dry batteries', probably because there is
much more room for investigation. Dry batteries that
are used in the commercial world today are practically
all of the same composition and general structure and
hence afford a smaller field for investigation.

A need for data based upon the behavior of
dry cells under various conditions has been felt, and
the purpose of this paper is to bring out the more
important points in the behavior of the batteries
under these various conditions, and to give a com-
parative test of the different makes of cells used
in the commercial world.

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A set of five cells was obtained from each of eleven different manufacturers. The sets were lettered A,B,C,D,E,F,H,I,K,L, and M respectively and the sets were subdivided into A1,A2,A3, A4,A5; B1,B2, ----- ----- M5. The cells will be referred to by letter and not by name.

After the cells were properly labelled each one was carefully weighed and the weights recorded before beginning the test.

The experimental data was obtained by four different test upon each set of cells. Each test will be explained in detail with the accompanying data, curves, and drawings irrespective of any other test.

No attempt will be made to give a detailed account of the chemical action that takes place in a dry cell under such conditions as are met with in the tests.

A Short History of Primary Cells.

At the close of the 18th century there
appeared no obvious connections between chemical
and electrical energy, the knowledge of electricity
being all together restricted to statical phenomena.
The first appearance of the voltaic cell arose
through a chance observation by Galvani. Late in
the 18th century Volta advanced the contact theory,
which assumes that when two different bodies being
conductors of electricity are in contact, there is
a force at the point of contact by which one of the
bodies gives a part of its natural portion of ele-
ctricity to the other body, which the latter takes
in addition to its own natural portion. Based upon
this theory, in 1799 Volta constructed a form of
dry battery known as Volta's Pile, consisting of
discs of zinc, wet cloth, and copper. These were
placed one above the other in the order named, so
that a piece of wet cloth was always encountered in
passing from zinc to copper, but not from copper to
zinc on continuing in the same direction. Thus a

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large number of cells were constructed and con-
nected together in series and a high electromotive
force resulted. After the appearance of the Volta's
Pile many new primary batteries were produced, most
of them being of the so called 'wet' type. Important
among this class of cells were the cells of Daniel in
1826; Grove in 1839. In 1868 the Leclanche cell
appeared and from this has developed the 'dry cell'.

A large number of attempts were made before
any of them proved to be successfull. Minotto used
sand and copper sulphate; Wolf, Keiser, and Schmidt
tried sawdust or cellulose; Desruellés filled a Le-
clanche cell with asbestos and spun glass; and Pol-
lok made use of a gelatine glycerine. The first real
successful dry cell was made by Gassner, and ap-
peared in 1888, and since then it has gradually dev-
eloped, until the value of this class of cells has
reached a state of high development and commercial
application.

The composition of the Gassner cell is
practically the same as that used by most manufact-

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urers today and consisted in general of oxide of
zinc 1 part by weight, chloride of zinc 1 part by
weight, sal-ammoniac 1 part by weight, plaster 3
parts by weight, water 2 parts by weight. The oxide
of zinc loosens and makes the electrolyte more
porous, thus affording easier paths for the inter-
change of gases, and thus diminishes the tendency
toward polarization at the electrodes.

"The office of water, one of the most im-
portant constituents of a primary battery, is two
fold; first, it is to dissolve and to hold in an
operative condition the chemicals by which the
voltaic action of the cell is excited and continued;
and second, it is to dissolve and diffuse the chem-
ical products resulting from that action. The am-
ount of water which any cell will contain stands
almost alone and nearly independent of the size and
form of the electrodes as the limiting measure of the
ultimate life of the battery at any work for which
it is fitted. The size and form and quantity of the
electrodes effect the temporary constancy of the cell,

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but the question whether, in any special service
for which the cell is adapted, it will continue
active for one month, six months, or a year, is an-
swered almost exclusively by the measured quantity
of water which the cell is made to contain. In all
batteries it is the loss of sal-ammoniac and the
accumulation of zinc oxides and ammonio-compounds
which determines the final failure of the battery
action. And consequently the displacement of the
available water of solution in any degree by ab-
sorbent solids will proportionately shorten the
active life of the cell.

Polarization.

Polarization is a condition due to the formation of a body, most commonly hydrogen, by electro-chemical decomposition upon the negative electrode, whereby a current in the opposite direction to the normal current of the cell is produced, and through which the normal current of the cell is greatly weakened.

The polarization action will not be as effective in a dry battery as in a wet battery since in a dry cell the electrolytes are made up of solid matter and the hydrogen bubbles have more diffi-culty in passing through the electrolyte in order to deposite themselves on the electrode. Also the amount of water from which the hydrogen is liberated is small in a dry cell in comparison to the amount in a wet cell. In the wet cell the bubbles of hydrogen find a ready path through the liquid.

Never-the-less there is some polarization action going on in a dry cell and in order to get the greatest amount of contact between the electrode and

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and the electrolyte this polarization action must be reduced to as low a value as possible. Several different methods have been adopted for this purpose.

Depolarizers.

Anything that can be put in the cell to reduce the action of polarization or to do away with it entirely is called a depolarizer. Aluminium chloride is a common depolarizer and in using it with dry cells a paste is prepared of a solution of aluminium chloride of 25 or 30 percent, and from 5 to 10 percent of magnesia; the paste conducts well and does not liquify when hot. The aluminium chloride does not attack the zinc, the negative electrode, which may also be made of aluminium. Another good depolarizer can be made by mixing a concentrated solution of ferric chloride with graphite and manganese dioxide, and compress the mixture in bags of linen. The electrolyte consists of chloride of zinc, ammonium, and magnesium, and is brought to the consistency of

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dough by being mixed with gum arabic, containing
arabic and metarabic acids, together with finely
ground bones. The depolarizer bag is forced within
the zinc cylinder into this dough, which latter pre-
vents diffusion of ferric chloride to the zinc.

Each manufacturer of dry cells uses his
own method for the prevention of polarization, and
the two methods cited above are by no means the ones
in general practice. But it was thought advisable
to give a few of the methods of doing away with polar-
ization in order to give the reader some idea of the
difficulties met with in the manufacture of a first
class primary cell of the dry type.

Part I.

The Intermittent Test.

The object of this test is to show the behavior of a dry cell when operating under conditions approaching the practical as near as can be assumed.

Figure I.

A scheme for connecting up the apparatus used in the intermittent test. An explanation of this scheme is to be found in the first part of the intermittent test.
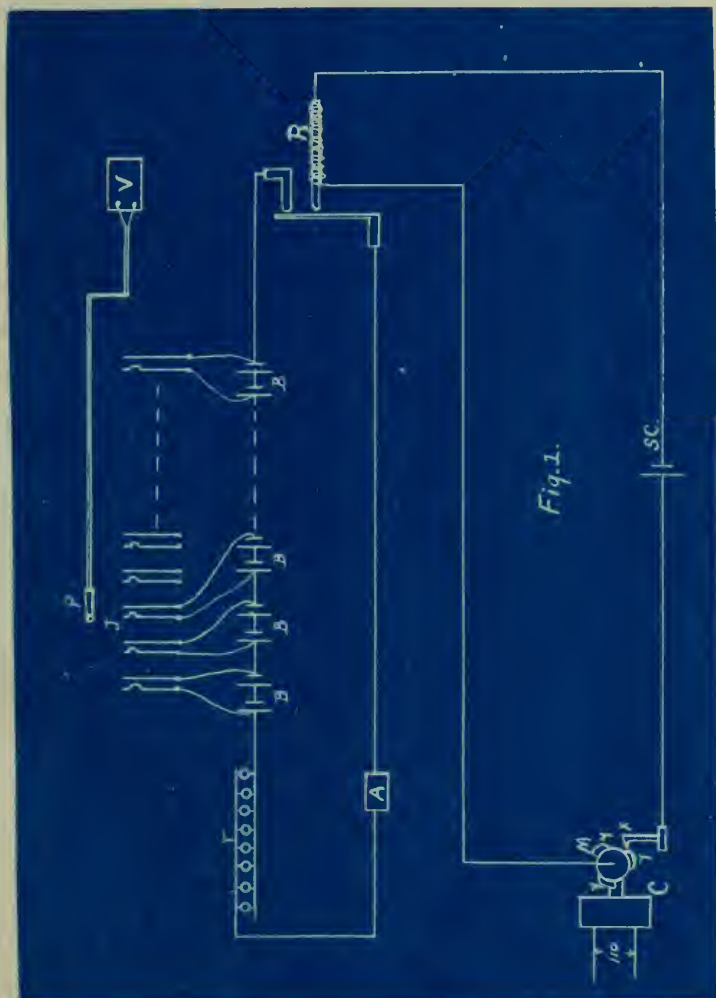
Fig. 1.

The Intermittent Test.

The intermittent test is no boubt the most
practical test that a dry cell can be submitted to;
because it is for this class of work that the dry
cell is manufactured. It was to this test that the
greater amount of time was given. The apparatus,
other than the cells necessary for obtaining the ex-
perimental data for this part consisted of the fol-
lowing;

> (1) Clock mechanism with intermittent
>   contact maker attached.
>
> (2) 0-5 Direct current direct reading ammeter.
>
> (3) 0-3   "   "   "   "   voltm'r.
>
> (4) Telephone jack with plug.
>
> (5) Incandescent lamps in parallel for
>   adjustment of resistance.
>
> (6) Relay for closing battery circuit.
>
> (7) Storage cell for exciting relay.

The apparatus was connected according to
the scheme shown in Fig 1. Two cells of each of the
different makes were chosen and connected in series

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through a resistance r, an ammeter A, and relay R.
The resistance r consisted of several thirty-two
candle-power incandescent lamps connected in parallel
so the resistance could be adjusted to any desired
value from about 12 ohms to 220 ohms. The greater
the number of lamps the less the resistance. Across
each group of cells was connected a telephone jack J.
The plug P was connected to the voltmeter V. By in-
serting the plug in the jack, the voltage across two
cells comprising a group can be read on the volt-
meter.

The closk mechanism was operated on a 110-
volt lighting circuit. In place of the minute hand
that is found on an ordinary clock was a brass disc
with three contact arms y,y,and y. The disc was con-
nected to one side of the magnetizing coil of the
relay R, while to the other side of the coil was con-
nected a storage cell SC to the contact point x,
secured to the base of the clock. The arms of the
contact maker are of sufficient size to close the

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circuit for a period of two minutes out of every
twenty minutes. When the point x comes in contact
with y, the circuit is closed through the storage
cell, which, in turn operates the relay closing the
battery circuit. Thus the cells discharge current,
the value of which depends on the resistance r. The
battery circuit will be closed as long as x is in
contact with y, in other words, the apparatus is so
timed that the cells will discharge for a period of
two minutes out of each twenty minutes, or one tenth
of the time.

At the beginning of the test the value of
the resistance r was adjusted to such a value that
the batteries gave out current to the value of 1.58
amperes. This value of current of course decreased
as the cells weakened.

During the test the values of the current
and the voltage were read once every twenty four
hours. The voltage was taken across two similiar
cells in series, and assuming the voltage of the two
cells to be the same, an assumption causing very
little error, if any, since the cells are of the same

make, the voltage as read by the voltmeter was div-
ided by two to get the voltage per cell. Knowing
the voltage and the current per cell, the watts were
calculated according to the formula

$$W = E \cdot I.$$

Then knowing the duration of the test and the fraction
of this time that the batteries were short cir-
cuited, (In this case it was one tenth of the time)
the watt-hours output from each cell was found by
using the formula

$$W = E \cdot I \cdot t,$$

where E is the voltage per cell, I is the current per
cell, and t is the time, in hours, that the cell was
on short circuit. Knowing now the total watt-hours
output, the watt-hours per cubic inch can be found
by dividing the total watt-hours by the volume of the
electrolyte in cubic inches. The volume of the ele-
ctrolyte being the volume of the cell less the volume
of the carbon.

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The test was carried on for twenty four days, during which time the current dropped from as high a value as 1.58 amperes to as low a value as .275 amperes, and the voltage dropped from as high a value as 1.52 volts to as low a value as .3625 volts, depending upon the make of cell. However in most of the cells the minimum value of voltage reached a value of about .9 volts. The test was continued no longer because the internal resistance of the cell had risen to such a high value that below .8 or .9 of a volt the cell is of little practical value in the commercial field. The difference in internal resistance before and after the test reached a value in one case of 6.32 ohms, while in another case it was only 1.59 ohms.

Data on Intermittent Test.

Battery "A"

Days	E	I	Hours on short circuit	Watt-hours	Watt-hours / cu in.
1	1.5075	1.5675	2.4	5.67	.2500
2	1.4450	1.3250	2.4	4.60	.2020
3	1.2800	1.2250	2.4	3.77	.1660
4	1.2700	1.0000	6.0	7.62	.3360
5	1.2525	.9500	2.4	2.85	.1280
6	1.2270	.8750	5.1	2.72	.1420
7	1.2175	.8750	2.4	5.43	.2440
8	1.1900	.7750	9.6	8.48	.3820
9	1.1700	.7250	2.4	2.03	.0915
10	1.1600	.6750	2.4	1.88	.0847
11	1.1125	.5800	2.4	1.54	.0695
12	1.1000	.5300	2.4	1.36	.0631
13	1.0750	.5300	2.4	1.40	.0613
14	1.0500	.4750	2.4	1.19	.0586
15	1.0500	.4250	2.4	1.07	.0482
16	1.0250	.3750	2.4	.92	.0414
17	.9750	.3500	2.4	.82	.0369
18	.9750	.3500	2.4	.82	.0369
19	.9625	.3260	2.4	.75	.0338
20	.9500	.3250	2.4	.74	.0333
21	.9500	.3250	2.4	.74	.0333
22	.9250	.3250	2.4	.72	.0324
23	.9000	.3100	2.4	.67	.0302
24	.8500	.3000	2.4	.66	.0299

Total- - - - 58.45

Average watt-hours per cubic inch = 2.63

Internal Resistance before test = 0.243

   "   "   after   "   = 5.000

Data on Intermittent Test.

Battery "B"

Days	E	I	Hours on short circuit	Watt-hours	Watt-hours / cu in.
1	1.4350	1.5674	2.4	5.40	.2580
2	1.2850	1.3250	2.4	4.09	.1955
3	1.2225	1.2250	2.4	3.59	.1715
4	1.1700	1.0000	5.0	7.02	.3360
5	1.1625	.9500	2.4	2.65	.1267
6	1.1425	.9250	2.4	2.53	.1210
7	1.1200	.8750	5.1	5.00	.2390
8	1.0625	.7750	9.6	7.90	.3770
9	1.0575	.7250	2.4	1.84	.0880
10	1.0450	.6750	2.4	1.69	.0810
11	.9875	.5800	2.4	1.37	.0655
12	.9500	.5300	2.4	1.21	.0579
13	.9250	.5300	2.4	1.18	.0565
14	.9200	.4750	2.4	1.05	.0502
15	.9000	.4250	2.4	.92	.0440
16	.8875	.3750	2.4	.80	.0381
17	.8625	.3500	2.4	.72	.0344
18	.8375	.3500	2.4	.70	.0335
19	.8375	.3250	2.4	.65	.0311
20	.8325	.3250	2.4	.65	.0311
21	.8250	.3250	2.4	.644	.0308
22	.8000	.3250	2.4	.625	.0299
23	.7750	.3100	2.4	.578	.0276
24	.7250	.3000	2.4	.523	.0274

Total - - - 53.33

Average watt-hours per cubic inch   2.55

Internal resistance before test   .307

"   "   after   "   2.517

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Data on Intermittent Test.

Battery "D"

Days	E	I	Hours on short circuit	Watt-hours	Watt-hours / cu in.
1	1.4300	1.5675	2.4	5.38	.2670
2	1.2350	1.3250	2.4	3.93	.1785
3	1.1825	1.2250	2.4	3.48	.1580
4	1.1050	1.0000	6.0	6.63	.3100
5	1.1000	.9500	2.4	2.50	.1135
6	1.0700	.9250	2.4	2.37	.1075
7	1.0375	.8750	5.1	4.62	.2100
8	1.0250	.7750	9.6	7.62	.2460
9	1.0250	.7250	2.4	1.79	.0814
10	1.0250	.6750	2.4	1.66	.0748
11	1.0200	.5800	2.4	1.42	.0646
12	1.0100	.5300	2.4	1.28	.0582
13	1.0075	.5300	2.4	1.28	.0582
14	1.0000	.4750	2.4	1.14	.0518
15	.9875	.4250	2.4	1.01	.0460
16	.9750	.3750	2.4	.88	.0400
17	.9700	.3500	2.4	.82	.0372
18	.9675	.3500	2.4	.81	.0368
19	.9675	.3250	2.4	.75	.0340
20	.9650	.3250	2.4	.74	.0336
21	.9650	.3250	2.4	.74	.0336
22	.9575	.3250	2.4	.72	.0327
23	.9500	.3100	2.4	.70	.03180
24	.9250	.3000	2.4	.67	.0804

Total- - 52.94

Average watt-hours per cubic inch   2.400

Internal resistance before test   .293

"   "   after   "   2.687

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Data on Intermittent Test.

Battery "E"

Days	E	I	Hours on short circuit	Watt-hours	Watt-hours / cu in.
1	1.4500	1.5675	2.4	5.45	.2600
2	1.3250	1.3250	2.4	4.20	.2005
3	1.2675	1.2250	2.4	3.73	.1785
4	1.2425	1.0000	6.0	7.45	.3560
5	1.2210	.9500	2.4	2.78	.1330
6	1.2175	.9250	2.4	2.70	.1290
7	1.1825	.8750	5.1	5.28	.2525
8	1.1775	.7750	9.6	8.75	.4180
9	1.1500	.7250	2.4	2.00	.0955
10	1.1500	.6750	2.4	1.86	.0890
11	1.1450	.6800	2.4	1.60	.0766
12	1.1250	.5300	2.4	1.43	.0685
13	1.0700	.5300	2.4	1.36	.0651
14	1.0250	.4750	2.4	1.17	.0560
15	1.0125	.4250	2.4	1.03	.0493
16	.9875	.3750	2.4	.89	.0426
17	.9000	.3500	2.4	.76	.0364
18	.8750	.3500	2.4	.74	.0354
19	.8750	.3250	2.4	.69	.0330
20	.8500	.3250	2.4	.66	.0315
21	.8375	.3250	2.4	.65	.0311
22	.8250	.3250	2.4	.64	.0306
23	.7750	.3100	2.4	.58	.0277
24	.7750	.3000	2.4	.57	.0271

Total - - -56.97

Average watt-hours per cubic inch   2.720

Internal resistance before test   .189

"   "   after   "   1.591

(20)

Data on Intermittent Test.

Battery "F"

Days	E	I	Hours on short circuit	Watt-hours	Watt-hours / cu in.
1	1.5200	1.5675	2.4	5.70	.2700
2	1.4250	1.3250	2.4	4.55	.2160
3	1.2650	1.2250	2.4	3.72	.1760
4	1.2375	1.0000	6.0	7.42	.3520
5	1.1865	.9500	2.4	2.70	.1280
6	1.1825	.9250	2.4	2.62	.1240
7	1.1250	.8750	5.1	5.02	.2480
8	1.1100	.7750	9.6	8.25	.3730
9	1.1000	.7250	2.4	1.91	.0908
10	1.1000	.6750	2.4	1.78	.0845
11	1.0825	.5800	2.4	1.51	.0716
12	1.0825	.5300	2.4	1.38	.0650
13	1.0675	.5300	2.4	1.36	.0645
14	1.0625	.4750	2.4	1.21	.0573
15	1.0625	.4250	2.4	1.08	.0512
16	1.0500	.3750	2.4	.95	.0460
17	1.0500	.3500	2.4	.88	.0416
18	1.0313	.3500	2.4	.87	.0412
19	1.0250	.3250	2.4	.80	.0379
20	1.0250	.3250	2.4	.80	.0379
21	1.0250	.3250	2.4	.80	.0379
22	1.0250	.3250	2.4	.80	.0379
23	.9850	.3100	2.4	.73	.0346
24	.9700	.3000	2.4	.70	.0332

Total- - 57.54

Average watt-hours per cubic inch   2.740

Internal resistance before test   .166

"   "   after   "   3.042

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Data on Intermittent Test.

Battery "H"

Days	E	I	Hours on short circuit	Watt-hours	Watt-hours / cu in.
1	1.4850	1.5675	2.4	5.60	.2745
2	1.4250	1.3250	2.4	4.53	.2220
3	1.2600	1.2250	2.4	3.70	.1815
4	1.2275	1.0000	6.0	7.38	.3620
5	1.2150	.9500	2.4	2.77	.1360
6	1.2063	.9250	2.4	2.68	.1315
7	1.1400	.8750	5.1	5.10	.2500
8	1.1075	.7750	9.6	8.25	.4040
9	1.1000	.7250	2.4	1.92	.0943
10	1.0725	.6750	2.4	1.74	.0854
11	1.0250	.5800	2.4	1.43	.0695
12	.9825	.5800	2.4	1.25	.0613
13	.9400	.5300	2.4	1.20	.0590
14	.9175	.4750	2.4	1.05	.0515
15	.8500	.4250	2.4	.87	.0476
16	.4750	.3750	2.4	.43	.0211
17	.4250	.3500	1.8	.27	.0133

Total- - -50.17

Average watt- hours per cubic inch 2.46

Internal resistance before test   .274

"   "   after   "   3.510

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Data on Intermittent Test.

Battery "I"

Days	E	I	Hours on short circuit	Watt-hours	Watt-hours / cu in.
1	1.4425	1.5675	2.4	5.42	.2660
2	1.1925	1.3250	2.4	3.97	.1950
3	1.2475	1.2250	2.4	3.52	.1730
4	1.1125	1.0000	6.0	6.67	.3270
5	1.0650	.9500	2.4	2.42	.1188
6	1.0750	.9250	2.4	2.39	.1172
7	1.0375	.8750	5.1	4.64	.2275
8	1.0325	.7250	9.6	7.70	.3780
9	1.0325	.7250	2.4	1.80	.0885
10	1.0250	.6750	2.4	1.66	.0815
11	1.0125	.5800	2.4	1.41	.0695
12	1.0075	.5300	2.4	1.28	.0629
13	.9925	.5300	2.4	1.26	.0618
14	.9875	.4750	2.4	1.12	.0550
15	.9850	.4250	2.4	1.01	.0495
16	.9825	.3750	2.4	.89	.0437
17	.9800	.3500	2.4	.83	.0407
18	.9800	.3500	2.4	.82	.0402
19	.9775	.3250	2.4	.76	.0373
20	.9750	.3250	2.4	.76	.0373
21	.9750	.3250	2.4	.76	.0373
22	.9725	.3250	2.4	.75	.0368
23	.9500	.3100	2.4	.71	.0348
24	.8250	.3000	2.4	.60	.0294

Total - - -53.15

Average watt-hours per cubic inch   2.610

Internal resistance before test   .248

"   "   after   "   4.310

(23)

Data on Intermittent Test.

Battery "K"

Days	E	I	Hours on short circuit	Watt-hours	Watt-hours / cu in.
1	1.4850	1.5675	2.4	5.58	.2790
2	1.3575	1.3250	2.4	4.31	.2155
3	1.2925	1.2250	2.4	3.80	.1900
4	1.2875	1.0000	6.0	7.70	.1350
5	1.2220	.9500	2.4	2.78	.1390
6	1.2500	.9250	2.4	2.78	.1390
7	1.2025	.8750	5.1	5.40	.2700
8	1.2025	.7750	9.6	8.95	.4475
9	1.1750	.7250	2.4	2.02	.1010
10	1.1625	.6750	2.4	1.89	.0945
11	1.1125	.5800	2.4	1.55	.0775
12	1.0575	.5300	2.4	1.34	.0670
13	1.0175	.5300	2.4	1.30	.0650
14	.9550	.4750	2.4	1.09	.0545
15	.9250	.4250	2.4	.94	.0470
16	.9125	.2750	2.4	.82	.0410
17	.8925	.3500	2.4	.75	.0375
18	.7250	.3500	2.4	.61	.0305
19	.7125	.3250	2.4	.56	.0288
20	.6750	.3250	2.4	.53	.0265
21	.6750	.3250	2.4	.53	.0265
22	.6625	.3250	2.4	.51	.0255
23	.5875	.3100	2.4	.44	.0220
24	.3625	.3100	2.4	.27	.0135

Total - - 56.45

Average watt-hours per cubic inch   2.823

Internal resistance before test   .238

"   "   after   "   4.000

(24)

Data on Intermittent Test.

Battery "L"

Days	E	I	Hours on short circuit	Watt-hours	Watt-hours / cu in.
1	1.4275	1.5675	2.4	5.35	.2500
2	1.2000	1.3250	2.4	1.59	.0745
3	1.0788	1.2250	2.4	3.41	.1595
4	1.0688	1.0000	6.0	6.41	.3000
5	.9925	.9500	2.4	2.26	.1060
6	.9675	.9250	2.4	2.19	.L025
7	.9625	.8750	5.1	4.28	.2000
8	.9500	.7750	9.6	7.06	.3300
9	.9375	.7250	2.4	1.63	.0763
10	.9325	.6750	2.4	1.51	.0706
11	.9300	.5800	2.4	1.29	.0603
12	.9125	.5300	2.4	1.16	.0542
13	.9125	.5300	2.4	1.16	.0542
14	.8938	.4750	2.4	1.02	.0476
15	.8875	.4250	2.4	.90	.0420
16	.8750	.3750	2.4	.79	.0369
17	.8625	.3500	2.4	.73	.0341
18	.8625	.3500	2.4	.73	.0341
19	.8500	.3250	2.4	.66	.0308
20	.3500	.3250	2.4	.66	.0308
21	.8425	.3250	2.4	.65	.0304
22	.8333	.3250	2.4	.64	.0299
23	.7825	.3100	2.4	.60	.0280

Total- - 46.68

Average watt-hours per cubic inch 2.180

Internal resistance before test   .430

    "   "   after   "   5.650

(25)

Data on Intermittent Test.

Battery "M"

Days	E	I	Hours on short circuit	Watt-hours	Watt-hours / cu in.
1	1.4800	1.5675	2.4	5.57	.2785
2	1.4425	1.3250	2.4	4.60	.2300
3	1.2850	1.2250	2.4	3.78	.1890
4	1.2400	1.0000	6.0	7.45	.3725
5	1.2300	.9500	2.4	2.80	.1400
6	1.1975	.9250	2.4	2.66	.1330
7	1.1375	.8750	5.1	5.07	.2525
8	1.1188	.7750	9.6	8.80	.4400
9	1.0825	.7250	2.4	1.89	.0945
10	1.0575	.6750	2.4	1.71	.0855
11	1.0150	.5800	2.4	1.41	.0705
12	1.0125	.5300	2.4	1.29	.0645
13	.9250	.5300	2.4	1.18	.0590
14	.8750	.4750	2.4	1.00	.0500
15	.8500	.4250	2.4	.87	.0435
16	.7500	.3750	2.4	.68	.0340
17	.4500	.3500	2.0	.04	.0200

Total - - - 50.80

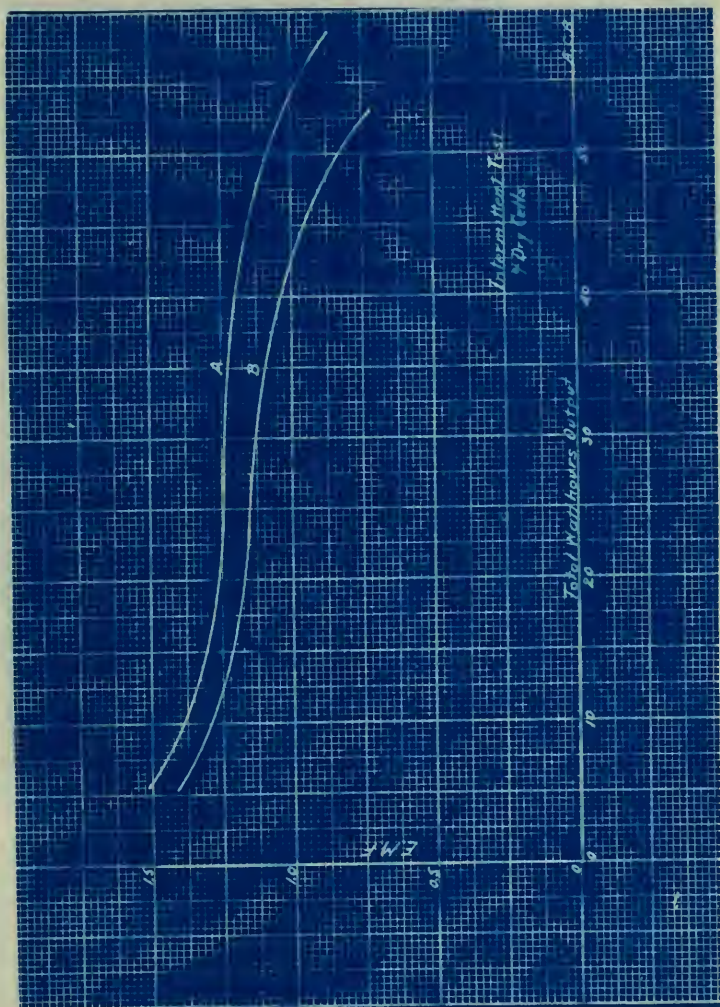Average watt-hours per cubic inch   2.541

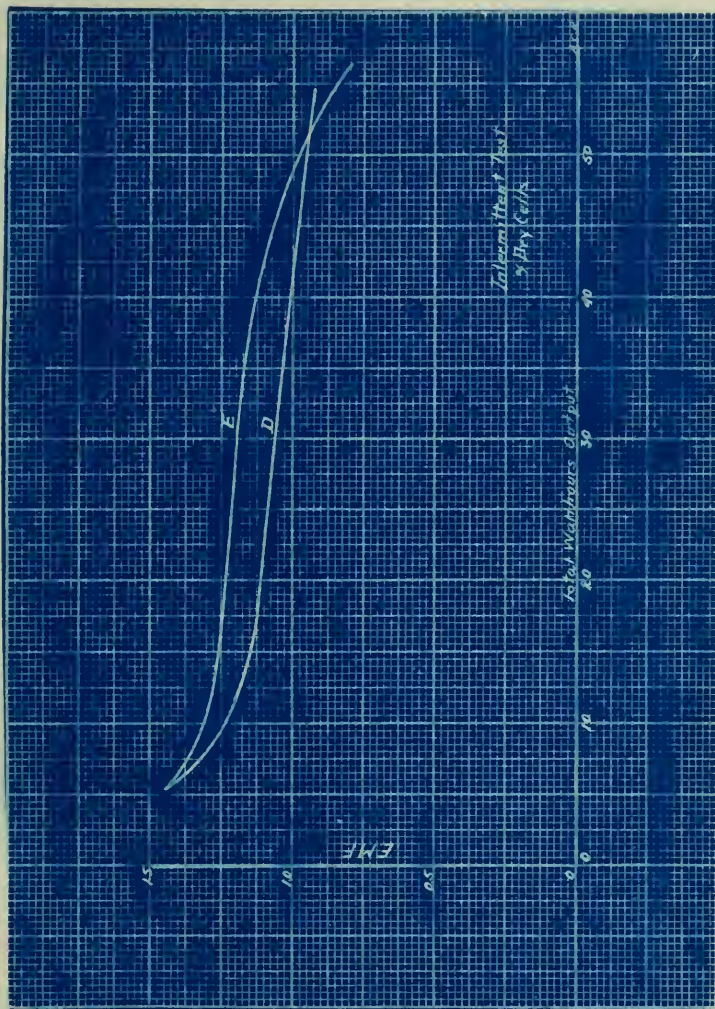Internal resistance before test   .160
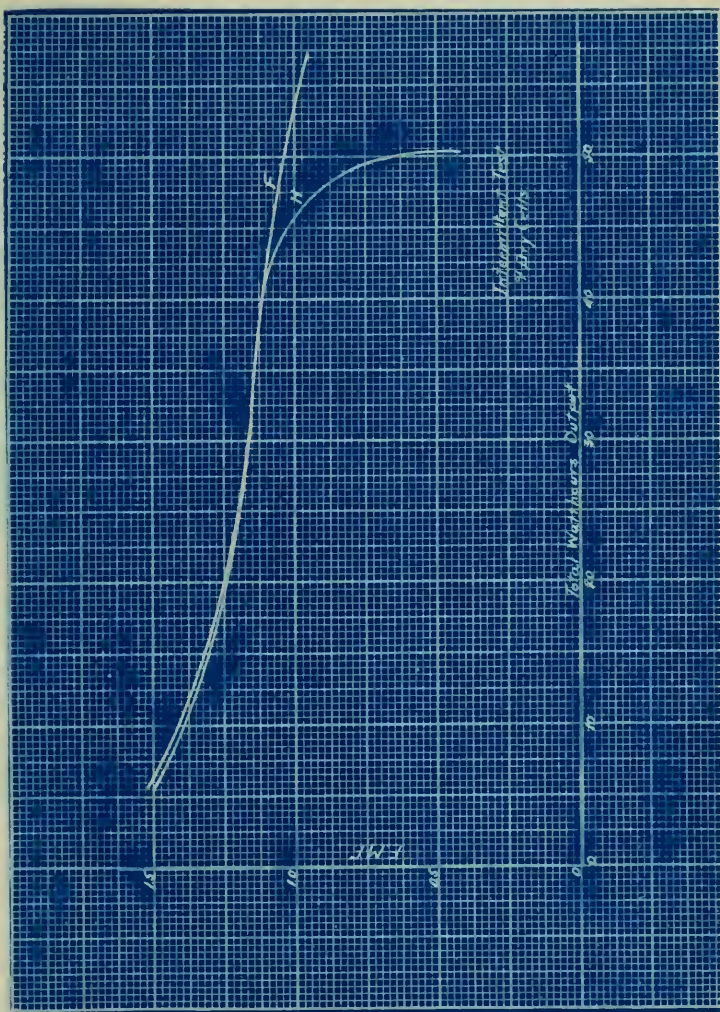
" " after "   - - - - -

Curves.

Intermittent Test.

Curves showing the relation between the watt-hours output and the open-circuit electro-motive force of the cells under test.
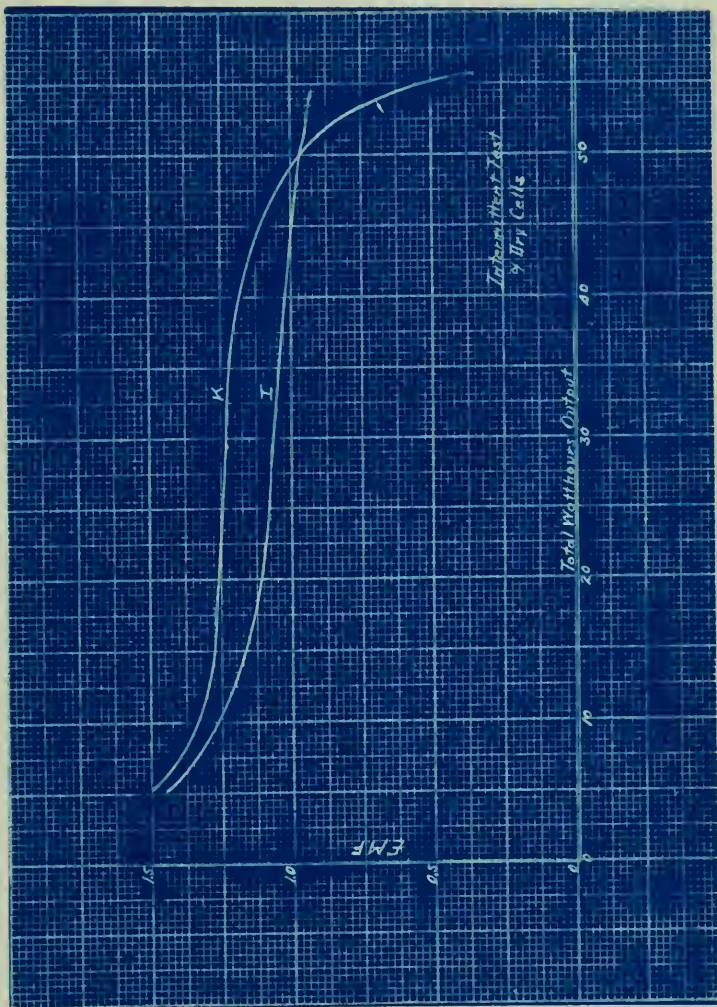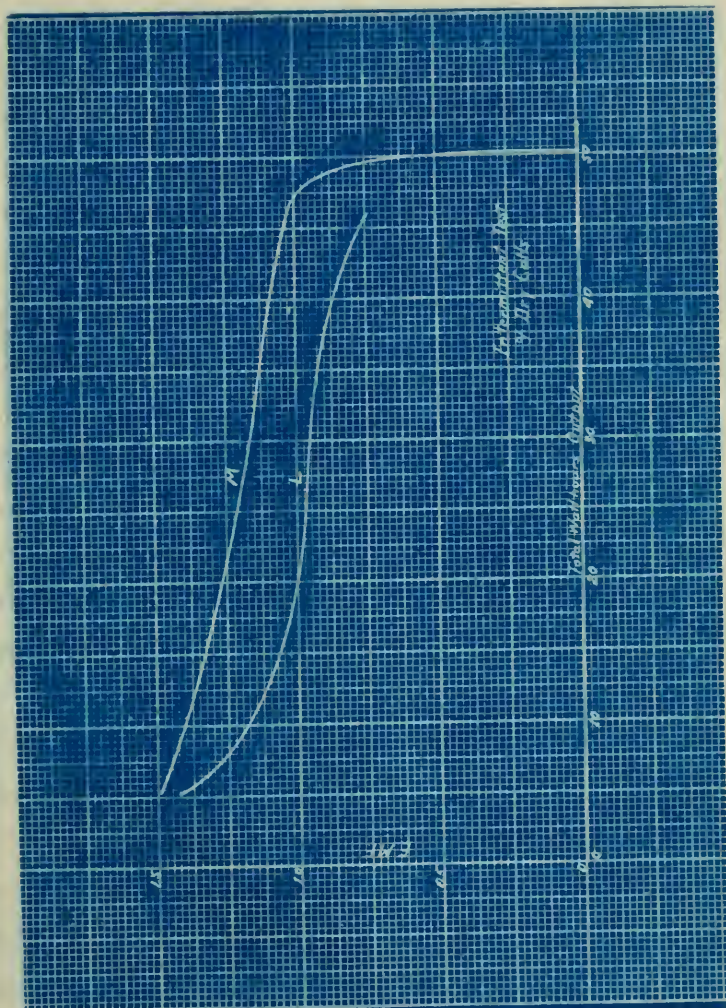
Laboratory Test of Dry Cells

Total Watt-hours Output

EMF

29

Intermittent Test
by Dry Cells

Total Watthours Output

EMF

30

By referring to the curves it will be seen that the value of the voltage of practically all of the cells drops with considerable rapidity for the first few watt-hours output. Between 20 watt-hours and 35 watt-hours discharge the value of voltage for cells A and B drops off very slowly, after which time it drops off quite rapidly again.

Between the values 15 watt-hours and 35 watt-hours the voltage of cell E drops slowly, after which it drops off more rapidly again.

Between the values 20 watt-hours and 55 watt-hours the voltage of D drops off quite gradually.

Between the values 30 watt-hours and 40 watt-hours cell F drops very slowly, more rapidly from there on.

Between 30 watt-hours and 40 watt-hours the voltage of cell H drops ver slowly, while from 40 watt-hours to 50 watt-hours it drops very rapidly, and at 50 assumes practically a vertical line.

(32)

Between 15 watt-hours and 35 watt-hours
the voltage of K drops off very slowly; from 35
watt-hours to 50 watt-hours it drops very rapidly.

Between 20 watt-hours and 50 watt-hours
the voltage of I drops off very gradually.

Between 20 watt-hours and 30 watt-hours
the voltage of L drops off slowly, more rapidly
from this point on.

Between 5 watt-hours and 47 watt-hours the
voltage of M drops off gradually, while after 47
watt-hours the voltage drops very rapidly, reach-
ing a zero value at 50 watt-hours.

Part II.

The Open Circuit Test.

The purpose of this test is to show the behavior of dry cells when standing idle.

The Open Circuit Test.

When dry cells are allowed to stand idle
there is a slight depreciation in their open-circut
electromotive force. This loss of potential is due
mostly to polarization in the cell itself, although
it is very probable that there are other causes due
to the chemical action of the cell. But since the
chemical action taking place in a dry cell was not
ascertained, it will be assumed that the loss of
voltage was due to the polarization.

The test consisted only of connecting a
voltmeter across one of the cells of each make and
reading the voltage of the cell as given by the
voltmeter. These readings were taken once every
twenty four hours for forty eight days. During that
length of time the voltage had dropped but a very
slight degree, ranging from 0 volts at the lowest
to .085 of a volt at the highest. The cells having
the greatest amount of polarization deteriorate
the fastest.

(34)

Assuming that the voltage drops more rap-
idly as the length of time increases, it would be
safe to say that in three months the voltage of the
cell that gave .085 of a volt drop for forty eight
days would have its open circuit electromotive force
decreased an amount equal to .2 of a volt. Now when
we stop to consider that when the value of voltage of
a dry cell reaches a value as low as .8 of a volt,
the cell is practically useless, with regards to
efficiency.

Therefore to get the highest efficiency
from a dry cell it should be put into use as soon
as possible after it has gone through the necessary
processes of manufacture.

Data on the Open Circuit Test.

Battery "A"

Taken each day for 48 days.

Volts	Volts	Volts
1.530	1.523	1.517
1.530	1.523	1.517
1.530	1.523	1.515
1.530	1.523	1.515
1.530	1.523	1.510
1.527	1.520	1.510
1.527	1.520	1.510
1.527	1.520	1.510
1.525	1.520	1.510
1.525	1.520	1.510
1.525	1.520	1.500
1.525	1.520	1.500
1.525	1.520	1.500
1.525	1.520	1.500
1.525	1.520	1.500
1.525	1.520	1.500

(36)

Data on the Open Circuit Test.

Battery "B"

Taken each day for 48 days.

Volts	Volts	Volts
1.460	1.450	1.430
1.460	1.450	1.430
1.460	1.450	1.435
1.460	1.450	1.435
1.460	1.450	1.430
1.460	1.450	1.430
1.460	1.450	1.430
1.460	1.450	1.430
1.460	1.450	1.425
1.460	1.450	1.425
1.455	1.445	1.425
1.455	1.445	1.420
1.455	1.445	1.420
1.455	1.445	1.420
1.450	1.445	1.420
1.450	1.445	1.420

Data on the Open Circuit Test.

Battery "D"

Taken each day for 48 days.

Volts	Volts	Volts
1.430	1.425	1.415
1.430	1.425	1.415
1.430	1.425	1.415
1.430	1.425	1.415
1.430	1.425	1.415
1.430	1.425	1.415
1.430	1.420	1.410
1.430	1.420	1.410
1.430	1.420	1.410
1.430	1.420	1.410
1.430	1.420	1.400
1.430	1.415	1.400
1.425	1.415	1.400
1.425	1.415	1.400
1.425	1.415	1.400
1.425	1.415	1.400

Data on the Open Circuit Test.

Battery "E"

Taken each day for 48 days.

Volts	Volts	Volts
1.430	1.425	1.410
1.430	1.420	1.410
1.430	1.420	1.410
1.430	1.420	1.405
1.430	1.420	1.405
1.430	1.420	1.405
1.430	1.420	1.405
1.430	1.420	1.405
1.430	1.420	1.405
1.425	1.420	1.400
1.425	1.420	1.400
1.425	1.420	1.400
1.425	1.420	1.400
1.425	1.415	1.400
1.425	1.415	1.400
1.425	1.415	1.400

Data on the Open Circuit Test.

Battery "F"

Taken each day for 48 days.

Volts	Volts	Volts
1.520	1.510	1.490
1.520	1.510	1.485
1.520	1.505	1.485
1.520	1.505	1.485
1.520	1.505	1.485
1.520	1.500	1.480
1.520	1.500	1.480
1.515	1.500	1.480
1.515	1.500	1.480
1.515	1.500	1.480
1.515	1.500	1.480
1.515	1.495	1.480
1.515	1.495	1.480
1.515	1.495	1.480
1.515	1.495	1.480
1.510	1.490	1.480

Data on the Open Circuit Test.

Battery "H"

Taken every twenty four hours.

Volts	Volts	Volts
1.500	1.495	1.480
1.500	1.495	1.480
1.500	1.495	1.475
1.500	1.495	1.475
1.500	1.490	1.470
1.500	1.490	1.470
1.500	1.490	1.470
1.500	1.490	1.470
1.500	1.490	1.470
1.500	1.490	1.465
1.500	1.490	1.465
1.500	1.485	1.465
1.500	1.485	1.460
1.500	1.485	1.460
1.495	1.480	1.460
1.495	1.480	1.460

(41)

Data on the Open Circuit Test.

Battery "I"

Taken each day for 48 days.

Volts	Volts	Volts
1.445	1.430	1.416
1.445	1.430	1.410
1.445	1.430	1.410
1.445	1.430	1.410
1.445	1.430	1.405
1.445	1.430	1.405
1.445	1.430	1.405
1.445	1.430	1.400
1.445	1.425	1.400
1.440	1.425	1.395
1.440	1.425	1.390
1.440	1.420	1.385
1.440	1.420	1.380
1.435	1.420	1.375
1.435	1.415	1.370
1.435	1.415	1.360

Data on the Open Circuit Test.

Battery "K"

Taken each day for 48 days.

Volts	Volts	Volts
1.480	1.470	1.440
1.480	1.470	1.435
1.480	1.470	1.435
1.480	1.470	1.430
1.480	1.470	1.430
1.480	1.465	1.425
1.480	1.465	1.425
1.480	1.460	1.420
1.480	1.460	1.415
1.475	1.460	1.410
1.475	1.455	1.410
1.475	1.455	1.405
1.475	1.450	1.400
1.475	1.445	1.400
1.475	1.445	1.400

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Data on the Open Circuit Test.

Battery "L"

Taken each day for 48 days.

Volts	Volts	Volts
1.420	1.420	1.420
1.420	1.420	1.420
1.420	1.420	1.420
1.420	1.420	1.420
1.420	1.420	1.420
1.420	1.420	1.420
1.420	1.420	1.420
1.420	1.420	1.420
1.420	1.420	1.420
1.420	1.420	1.420
1.420	1.420	1.420
1.420	1.420	1.420
1.420	1.420	1.420
1.420	1.420	1.420
1.420	1.420	1.420
1.420	1.420	1.420

Data on the Open Circuit Test.

Battery "M"

Taken each day for 48 days

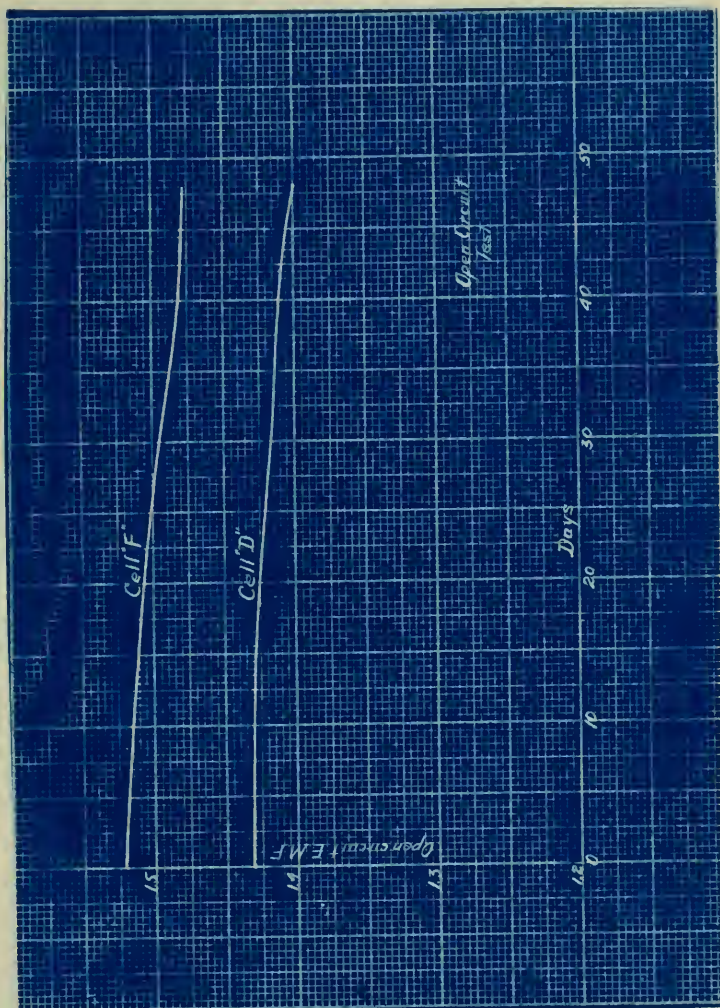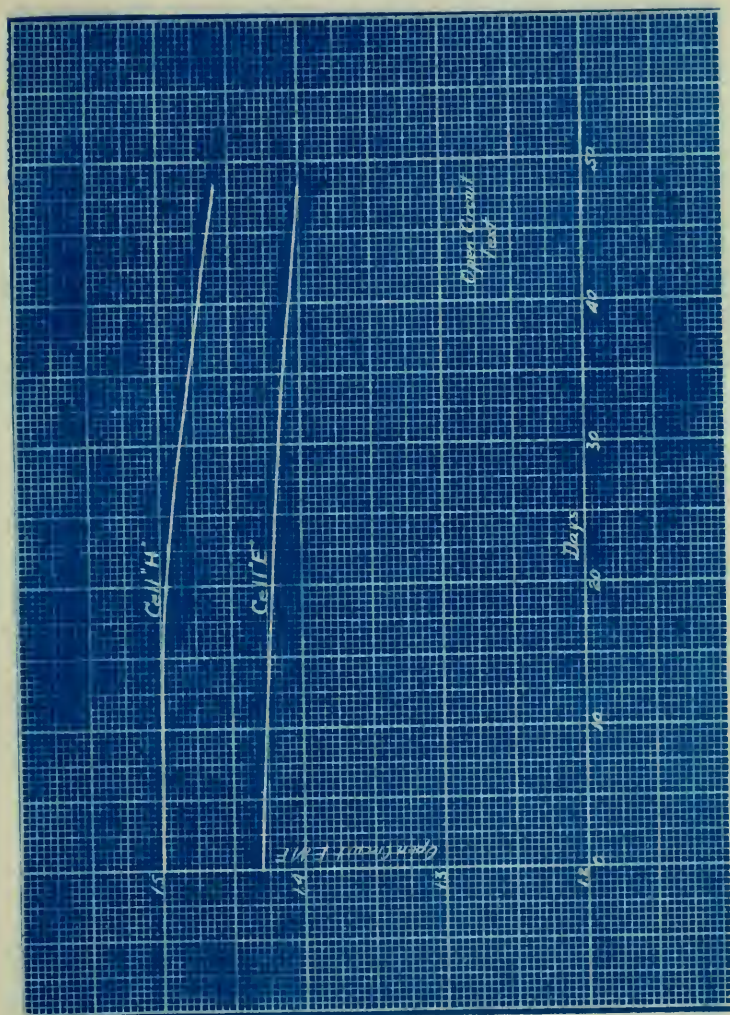| Volts	Volts	Volts
1.450	1.440	1.420
1.450	1.440	1.420
1.450	1.435	1.415
1.450	1.435	1.415
1.450	1.435	1.415
1.450	1.435	1.415
1.450	1.435	1.410
1.450	1.435	1.410
1.445	1.435	1.410
1.445	1.430	1.400
1.445	1.430	1.400
1.445	1.430	1.400
1.445	1.430	1.400
1.445	1.425	1.400
1.445	1.425	1.400

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Curves.

Open Circuit Test.

The following curves show the relation between the open circuit electromotive force and the length of time in days of the cells under test.
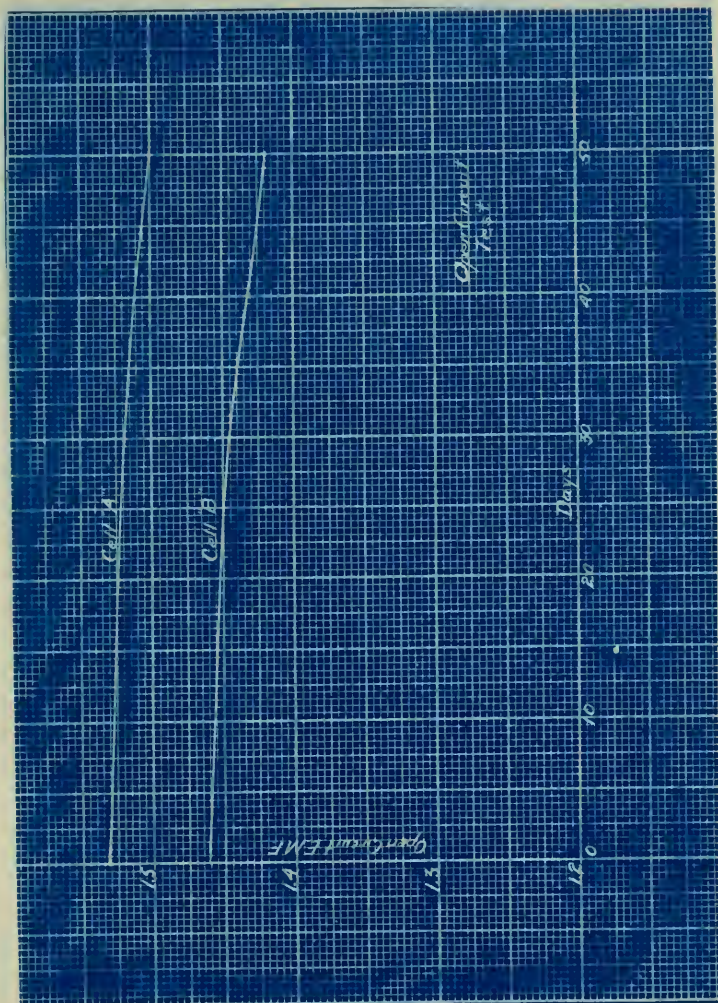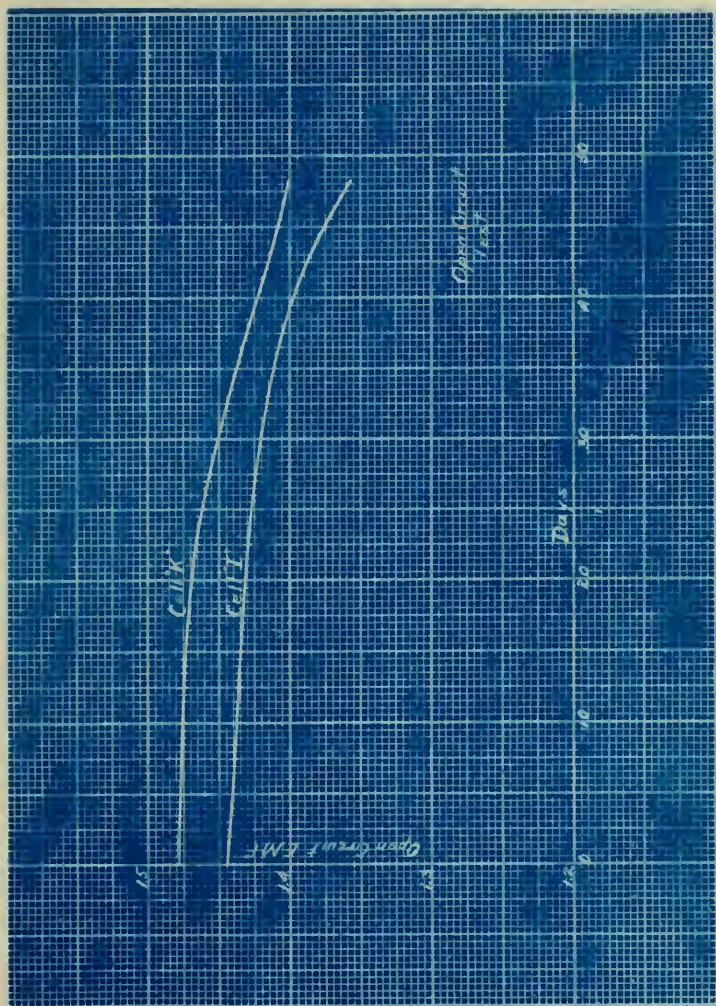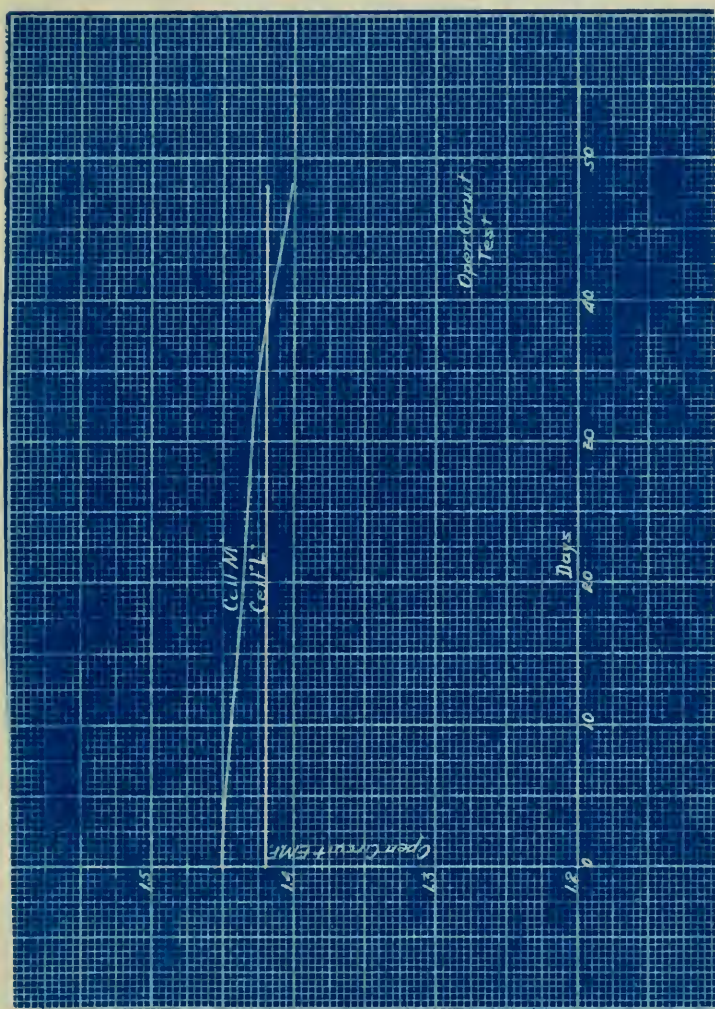
Cell A

Cell B

Open Circuit Test #

Days

Open Circuit EMF

1.5

1.4

1.3

1.2

0   10   20   30   40   50

Cell "F"

Cell "D"

Open circuit E.M.F.

Open Circuit
Test

Days

.15

.14

.13

.12

0   10   20   30   40   50

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Part III.

The Temperature Test.

The purpose of this test is to show the be-
havior of dry cells when submitted to an increasing
temperature; to show the effect of temperature upon
the internal resistance of the cell.

Figure II.

A sectional view of the apparatus for vary-
ing the temperature; and a scheme of the connections
for the temperature test.

Fig 2
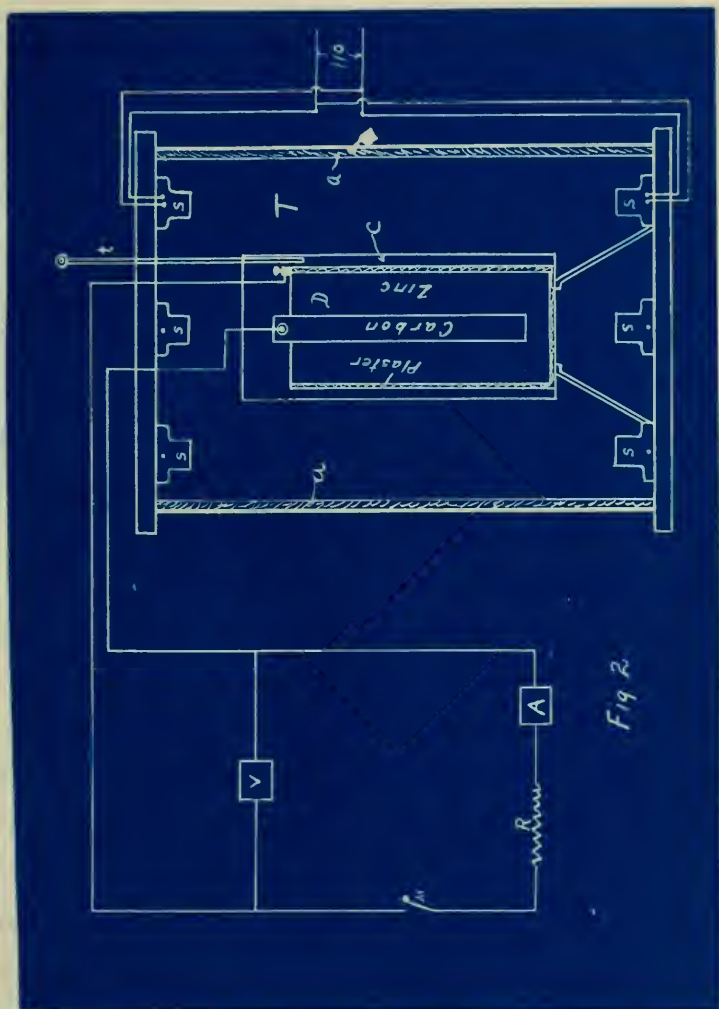
The Temperature Test.

Dry cells are very often used in places where the temperature of the surrounding atmosphere is much above normal room temperature. Ordinarily dry cells are used where the temperature is very close to normal room temperature.

This test was carried on by varying the temperature of the cell and taking readings of the open circuit electromotive force, the closed circuit electromotive force, and the current at each variation.

The apparatus was set up according to the scheme shown in Figure 2. T is a galvanized iron tank with heavy wooden top and base. The galvanized iron part of the outer tank was lined with asbestos a. Inside this tank, supported on legs, is a smaller galvanized iron tank C, inside of which is placed the dry cell D to be tested. Close to the outer edge of the top and the base of the tank T is a circle of lamp sockets S, into which are placed incandescent lamps. These lamps are connected to a 110-volts

(52)

lighting circuit, and by taking out or putting in lamps the temperature in the chamber C can be regulated. Through a hole in the cover and down into the chamber C is a thermometer for measuring the temperature.

In series with the cell D is connected an ammeter A, a resistance R which is known, and a switch M. Across the cell is connected the voltmeter V. With the switch M open the voltmeter reads the open circuit voltage of the cell, and with switch M closed the voltmeter reads the closed circuit voltage of the cell. Knowing the open and the closed circuit voltage, the value of the resistance R, and the current flowing through the ammeter, the internal resistance of the cell can be calculated by the formula $r = \frac{E_o - E_c}{I} R$. E_c will always be less than E_o due to the drop of electromotive force in the cell when it is discharging an appreciable amount of current.

The first set of readings was taken at about 70F°, room temperature. By means of the lamps the

temperature was varied in increments up to nearly 300°. A set of readings was taken at each variation, and the internal resistance calculated each time. However, before any readings were taken the cell under test was allowed to remain at that temperature until there was no doubt about the temperature being the same throughout all parts of the cell.

At about 225F° the sealing compound of the cells melted, but as it formed a thick layer over the top of the electrolyte, it can be safely assumed that it caused no error in the results.

One of each of the different makes of cells was tested and all the data, together with the curves is recorded on the following pages.

Data on the Temperature Test.

Battery "A"

Temp. $F°$	E_o	E_c	I	R
70	1.500	1.410	.80,0	.1995
197	1.500	1.430	.80,0	.1550
258	1.490	1.436	.80,0	.1330
240	1.466	1.410	.80,0	.1220

Rise in temperature - - - - - - - - - - - - -170°

Maximum fall in open circuit voltage - - -   .034

Maximum rise in closed circuit voltage - -   .026

Maximum fall in current - - - - - - - - - - - 0

Decrease in internal resistance - - - - - - .0775

Data on the Temperature Test.

Battery "B"

Temp. F°	E_o	E_c	I	R
75	1.420	1.290	.720	.3200
148	1.434	1.300	.725	.3180
153	1.440	1.303	.725	.3225
170	1.444	1.320	.730	.3050
209	1.446	1.322	.730	.3050
254	1.430	1.342	.750	.2815

Rise in temperature - - - - - - - - - - - - 179°

Maximum rise in open circuit voltage - - - .026

Maximum rise in closed circuit voltage - - .052

Maximum rise in current - - - - - - - - - - .030

Decrease in internal resistance - - - - - - .091

(56)

Data on the Temperature Test.

Battery "D"

Temp. F°	E_o	E_c	I	R
74	1.400	1.276	.700	.3140
158	1.420	1.290	.720	.3200
183	1.430	1.296	.720	.3300
212	1.434	1.290	.710	.3595
235	1.434	1.310	.705	.3110

Rise in temperature - - - - - - - - - - - - 161°

Maximum rise in open circuit voltage - - - .034

Maximum rise in closed circuit voltage - - .034

Maximum rise in current - - - - - - - - - - .020

Maximum rise in internal resistance - - - - .0485

(57)

Data on the Temperature Test.

Battery "E"

Temp. F°	E_o	E_c	I	R
75	1.406	1.304	.720	.2510
115	1.418	1.320	.730	.2475
130	1.422	1.328	.730	.2280
151	1.426	1.336	.730	.2180
182	1.426	1.340	.740	.2065
210	1.436	1.360	.750	.1795
235	1.434	1.366	.750	.1605

Rise in Temperature - - - - - - - - - - - - 160°

Maximum rise in open circuit voltage- - - - .030

Maximum rise in closed circuit voltage- - - .062

Maximum rise in current - - - - - - - - - - .030

Decrease in resistance - - - - - - - - - - .0905

(58)

Data on the Temperature Test.

Battery "F"

Temp. F°	E_o	E_c	I	R
68	1.480	1.394	.770	.1975
105	1.480	1.396	.772	.1925
146	1.482	1.402	.775	.1830
191	1.482	1.416	.780	.1498
209	1.434	1.346	.750	.2020
235	1.434	1.360	.750	.1750

Rise in temperature - - - - - - - - - - - - 167°

Maximum rise in open circuit voltage- - - - .048

Maximum fall in closed circuit voltage- - - .070

Maximum fall in current - - - - - - - - - - .030

Decrease in internal resistance - - - - - - .027

Data on the Temperature Test.

Battery "H"

Temp. F°	E_O	E_C	I	R
70	1.460	1.364	.760	.2250
101	1.464	1.378	.770	.1980
147	1.474	1.396	.775	.1780
190	1.480	1.404	.780	.1725
255	1.480	1.416	.786	.1440

Rise in temperature - - - - - - - - - - - - 185°

Maximum rise in open circuit voltage- - - - .020

Maximum rise in closed circuit voltage- - - .052

Maximum rise in current - - - - - - - - - - .026

Decrease in internal resistance - - - - - - .080

(60)

Data on the Temperature Test.

Battery "I"

Temp. F°	E_O	E_C	I	R
75	1.360	1.272	.700	.2230
130	1.430	1.345	.712	.2115
192	1.440	1.358	.720	.2020
232	1.460	1.380	.731	.1935
257	1.466	1.390	.738	.1820
281	1.470	1.395	.740	.1795

Rise in Temperature - - - - - - - - - - - - 206°

Maximum rise in open circuit voltage- - - - .110

Maximum rise in closed circuit voltage- - - .123

Maximum rise in current - - - - - - - - - - .040

Decrease in internal resistance - - - - - - .0435

(61)

Data on the Temperature Test.

Battery "K"

Temp. $F°$	E_o	E_c	I	R
75	1.400	1.300	.710	.2490
130	1.410	1.312	.720	.2410
153	1.422	1.324	.728	.2380
180	1.428	1.336	.737	.2210
212	1.431	1.341	.750	.2125
250	1.440	1.364	.759	.1770

Rise in temperature - - - - - - - - - - - -   175°

Maximum rise in open circuit voltage-- - -   .040

Maximum rise in closed circuit voltage- - -   .064

Maximum rise in current - - - - - - - - - -   .049

Decrease in internal resistance - - - - - -   .072

(62)

Data on the Temperature Test.

Battery "L"

Temp. F°	E_o	E_c	I	R
74	1.420	1.330	.720	.2210
124	1.430	1.341	.729	.2160
143	1.438	1.350	.740	.2110
180	1.452	1.365	.744	.2070
221	1.460	1.380	.748	11895
270	1.472	1.400	.752	.1695

Rise in Temperature - - - - - - - - - - - - - 196°

Maximum rise in open circuit voltage- - - - .052

Maximum rise in closed circuit voltage- - - .070

Maximum rise in current - - - - - - - - - - - .032

Decrease in internal resistance - - - - - - .0515

Data on the Temperature Test.

Battery "M"

Temp. F°	E_o	E_c	I	R
70	1.400	1.320	.700	.2030
127	1.407	1.327	.710	1995
147	1.420	1.340	.717	.1975
183	1.430	1.354	.721	.1840
219	1.450	1.374	.742	.1985
267	1.452	1.378	.750	.2050

Rise in temperature - - - - - - - - - - - - - 197°

Maximum rise in open circuit voltage- - - - .052

Maximum rise in closed circuit voltage- - - .058

Maximum rise in current - - - - - - - - - - .050

Decrease in internal resistance - - - - - - .019

Curves.

The Temperature Test.

Curves showing the relation between the
internal resistance of the cells and the temperature
at which the resistances were taken. The curves
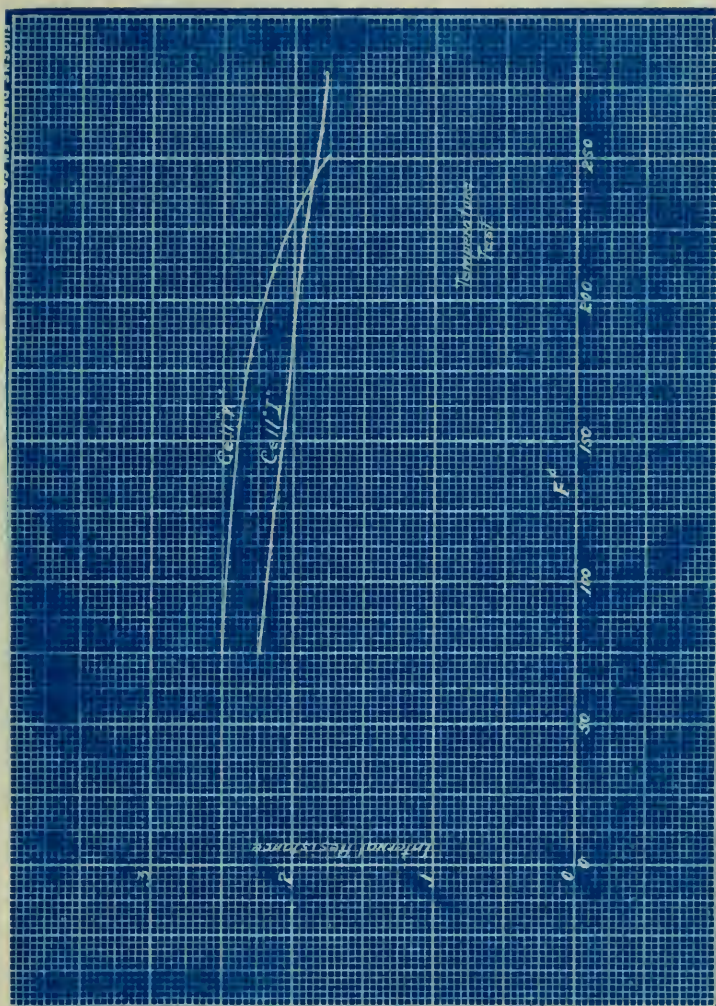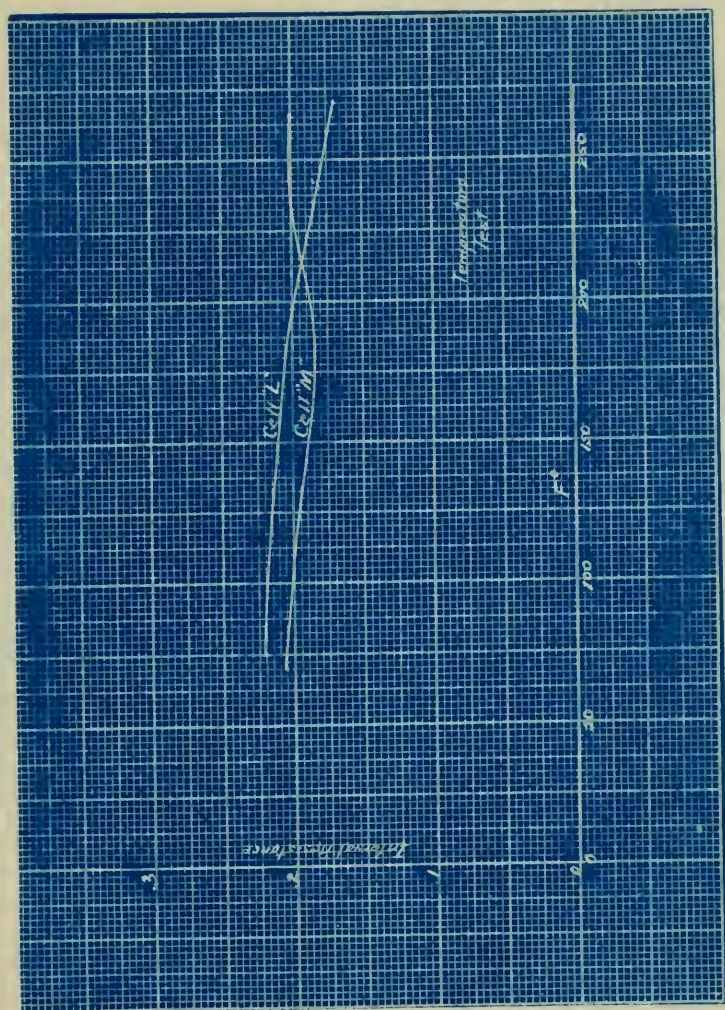are self evident and need no explanation.
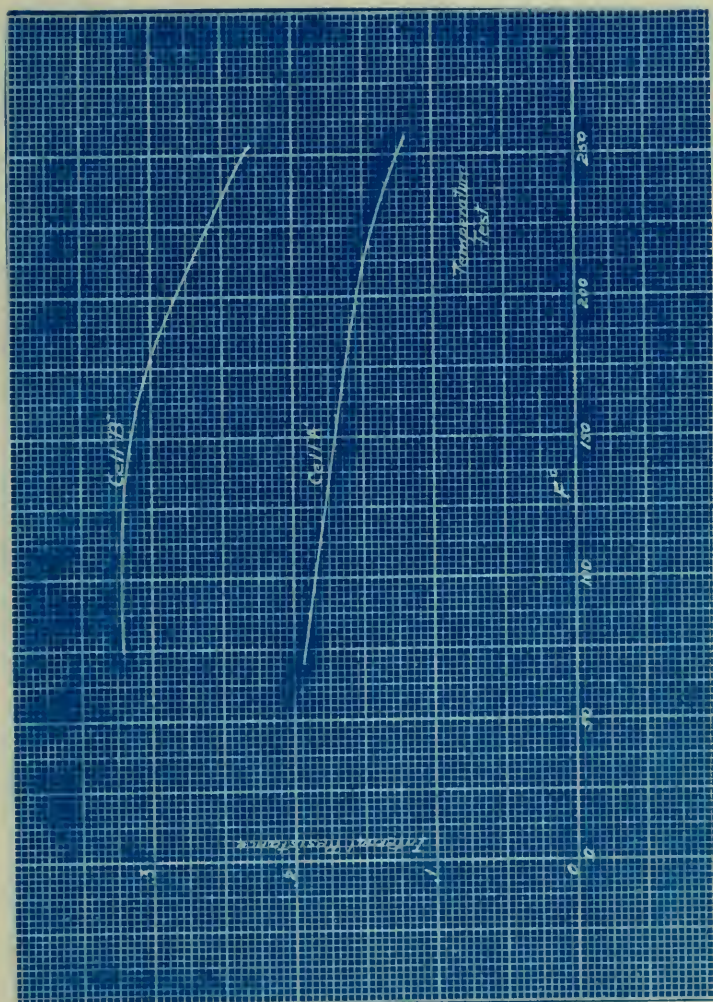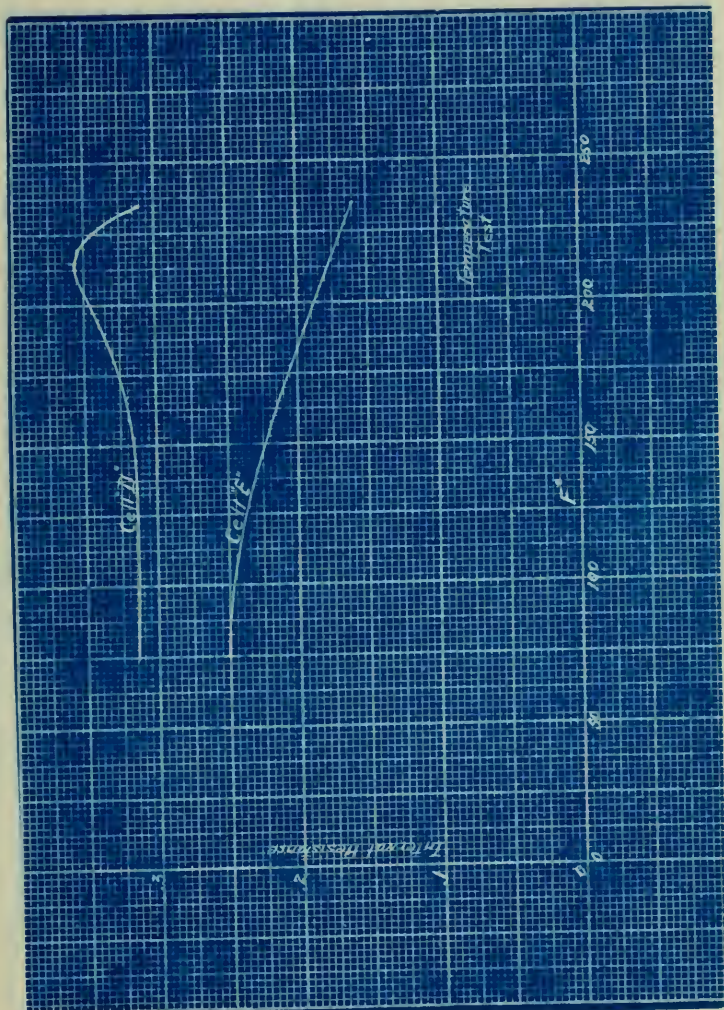
Cell B

Cell A

Internal Resistance

Temperature
Test
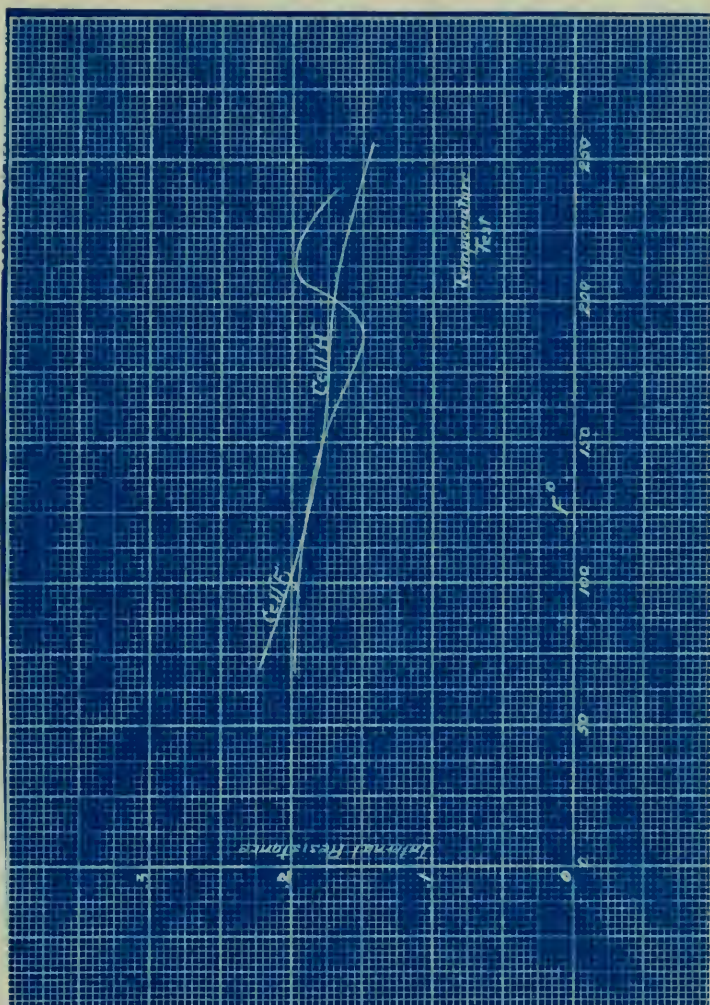
Part IV.

The Recuperative Test.

The purpose of this test is to show how much and with what rapidity a dry cell will regain its power when left standing idle after it has been short circuited through a resistance.

The Recuperative Test.

The recuperative test consisted merely of
connecting the cell to be tested in series with a
resistance and an ammeter and allowing the cell to
remain under these conditions for a length of time.
The cells were connected in series with an ammeter
and a resistance and allowed to stand with the cir-
cuit closed for a little over three hours.

After the closed circuit voltage had drop-
ped somewhat below one volt the circuit was opened
and readings of the open circuit voltage taken every
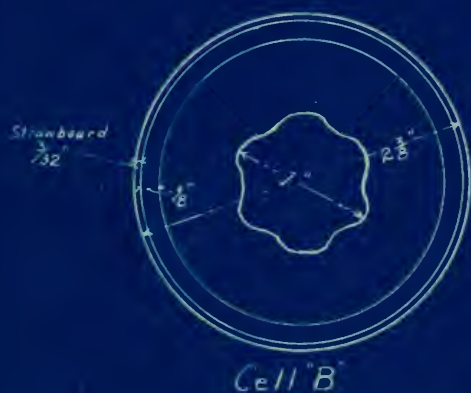twenty minutes until 2 hours and 40 minutes of time
had elapsed.

The voltage of cell "A" increased form 1
to 1.17 volts; "B" from .92 to 1.11 volts; "C" from
0 to .98 volts; "D" from .87 to 1.06 volts; "E" from
1.02 to 1.182 volts; "F" from .98 to 1.14 volts;
"H" from .98 to 1.182 volts; "I" from .85 to 1.02
volts; "K" from 1.03 to 1.21 volts; "L" from .85 to
1.042 volts; and "M" from 1.0 to 1.17 volts.

Cell "C" dropped to zero voltage after it
had been in the circuit for less than 2 hours; but
it recuperated from 0 to .98 volts, showing that
for other than short intermittent uses it is of no
practical value, and if it were not for its quick
recovery it would be absolutely useless. The cell
was omitted in the other tests for the reason of its
low, short circuited life. The other cells gave all
about the same results and it can be safely assumed
that these results are an average value for all
makes of dry cells.

Part V.

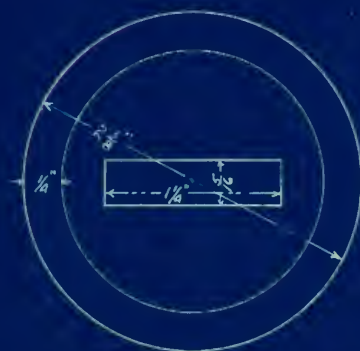Five plates showing a cross-sectional
view of the cells under test.

Cell "A" was drawn with the sections
cross-sectioned in order to give the reader an idea
of the arrangement of the parts of a dry cell. The
outline and dimensions of the other cells are given
and by referring to cell "A" the various dimen-
sions are explained.

Cell "A"

Zinc

Plaster
3/32

Carbon
3/4

2 3/8"

Electrolyte

Cell "B"

Strawboard
7/32"

1/8"

1"

2 3/8"

Plate 1.

Cell "C"

Cell "D"

Cell "E" same as "B"

Cell "F"

Cell "H"

Plate 3

74

Cell "I"

Cell "K"

Plate 4

75

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Cell "M"

Cell "L"

Plate 5.

76
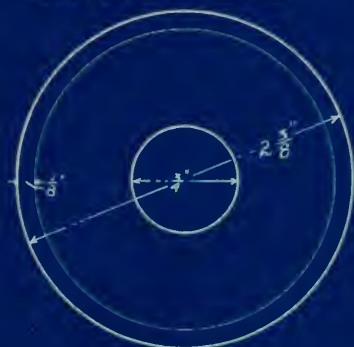
Part VI.

A Short Summary of the Tests.

Summary.

A thoroughly practical set of tests on dry cells having been explained in detail it may be well now to give a summary of the most important points brought out. Although only 10 makes of cells were tested, (only 10 makes were tested since the 11th was found to be too short lived to give any good practical results) it can be said that these are a fair representation of all the makes of dry cells on the market today.

In making a summary of the data it may be well to tabulate the data of the three tests as follows, and by reading the tables one can tell at a glance the performance of each of the makes of cells.

The Intermittent Test.

Make of cell.	Internal res.	Watt-hours del.	Watt-hours / cu in.
A	.243	58.45	2.63
B	.307	53.33	2.55
D	.293	52.94	2.40
E	.189	56.97	2.72
F	.166	57.54	2.74
H	.274	50.17	2.46
I	.248	53.15	2.61
K	.238	56.45	2.32
L	.430	46.68	2.18
M	.160	50.80	2.54

The Open Circuit Test.

Make of cell	Volts at beginning	Volts after 48 days
A	1.530	1.500
B	1.460	1.420
D	1.430	1.400
E	1.430	1.400
F	1.520	1.480
H	1.500	1.460
I	1.445	1.360
K	1.480	1.400
L	1.420	1.420
M	1.450	1.400

The Recuperative Test.

Make of cell	Open circuit e.m.f.after 3.16 hours output	Open circuit e.m.f.after 2.16 hours recovery.
A	1.00	1.170
B	.92	1.110
C	0	.980
D	.87	1.060
E	1.02	1.182
F	.98	1.140
H	.98	1.182
I	.85	1.020
K	1.03	1.210
L	.85	1.042
M	1.00	1.170

-*FINIS*-